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National Telecommunications and
Information Administration
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Mr. Edmond J. Thomas
Chief, Office of Engineering and Technology
Federal Communications Commission
445 - 12th Street, S.W.
Washington, DC 20554

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Federal Communications Commission
Office of the Secretary

Reference. Notice of Proposed Rulemaking, *Allocations and Service Rules for the 71-76 GHz, 81-86 GHz, and 92-95 GHz Bands, Loea Communications Corporation Petition for Rulemaking*; WT Docket No. 02-146, RM-10288


Dear Mr. Thomas:

In the NTIA Reply Comments to the referenced Notice of Proposed Rulemaking, NTIA indicated that a study had been initiated on sharing between the radiolocation service and the fixed service in the 92-95 GHz band. This sharing study has been completed and is attached for inclusion in the public record.¹

The sharing study only addresses interactions between an airborne radar system and a type of point-to-point fixed link similar to a system proposed by Loea. NTIA understands that other scenarios are possible, and may include ground-based point-to-multipoint systems.

If you have any questions regarding this study, please contact Mr. Gerald Hurt of my staff. He may be reached at 202-482-4107.

Sincerely,


Fredrick R. Wentland
Acting Associate Administrator
Office of Spectrum Management

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¹ Cou-Way Wang. U.S. Department of Commerce. National Telecommunications and Information Administration, Technical Note 03-1, *Frequency Sharing Between the Fixed and Radiolocation Services in the 92 to 95 GHz Band*. February, 2003

NTIA-TN-03-1

Frequency Sharing Between the Fixed and Radiomobility Services in the 92 to 95 GHz Band

Con-Wey Wang

February 2003

U.S. DEPARTMENT OF COMMERCE

NTIA

National Telecommunications and
Information Administration

NTIA-TN-03-1

Frequency Sharing Between the Fixed and Radiolocation Services in the 92 to 95 GHz Band

Cou-Way Wang

February 2003

Acknowledgement

The author would like to thank Karl Nebbia, Russell Slye, Gerald Hurt, Robert Hinkle, Gary Patrick and Suzette Williams of National Telecommunications and Information Administration for their suggestions and comments.

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Frequency Sharing Between the Fixed and Radiolocation Services in the 92 to 95 GHz Band

Summary

This report examines the frequency sharing condition between the fixed service (FS) and radiolocation service (RLS) in the 92-95 GHz band. This study covers only the case of interference from an airborne RLS system, using ground mapping radar techniques, to a point-to-point FS system. The study is preliminary in nature because it addresses only typical parameters and does not consider the full range of possible technical parameters and deployment scenarios. However, for the cases considered, the study shows that compatible co-frequency sharing between FS and RLS systems is possible with minimal restrictions on either system. The study suggests that airborne RLS systems transmitting at altitudes below 3 km (10k feet) and/or antenna depression angles of less than 15° may result in elevated levels of interference to FS systems. The study further suggests that point-to-multipoint FS systems, if used in this band, may experience significantly higher levels of interference than the point-to-point FS systems addressed in this study. It is shown that the interference power can be substantial in main beam coupling situations; however, the probability of those situations is well below accepted short-term criteria established by the International Telecommunication Union (ITU) for FS systems.

1. Introduction

The 92-95 GHz band is allocated to both the FS and RLS on primary basis. For lower frequency bands, numerous studies and reports already cover interference analysis and mitigation techniques between the FS and radiodetermination service (RDS), which includes RLS and radionavigation service. However, these analysis and mitigation techniques are not applicable to the envisioned 92-95 GHz FS systems in fiber-optic communication rates, i.e., Gbps. This study analyzes the interference from an airborne RLS system to a FS system.

11. Interference Analysis

Currently there are few FS or airborne RLS systems operating in the 92-95 GHz band. Therefore, their technical parameters must be assumed in order to investigate the potential interference problem. Technical parameters of some of the FS and airborne RDS systems in the millimeter wavelength range (30 GHz to 300 GHz) are presented in **Annex A**. From these data, the technical parameters for the FS and airborne RLS systems in the 92-95 GHz band are derived and presented in **Annex A**. In particular, the FS system parameters come from a

system being developed to provide services in fiber-optic communication rates in the 71-76 GHz band, and the airborne RLS system parameters come from a representative air-to-ground radar targeting system.

Annex A first presents the FS system link budget, which calculates the carrier power and the fade margin provision. Since radio transmission in the 92-95 GHz band suffers significant fading in inclement weather, a FS system must be designed with significant fade margin provision to achieve the desired availability objective. In the study case in Annex A, the FS system clear-sky carrier-to-noise ratio (C/N) is 48 dB, providing a system margin of 30 dB. For the interference protection, a large system margin is capable of yielding acceptable $(C/N)_{\text{total}}$ value even if the interference-to-noise ratio (I/N) value is relatively high. In this study this margin is used in Annex D to derive the IN criteria for the FS system.

The interference analysis in Annex A calculates the I/N as a function of distance between a FS station and an airborne RLS station, with the FS receive antenna elevation angle and the airborne RLS station altitude as additional parameters. The result shows that the interference power becomes substantial when:

1. the airborne station is at low altitude (3 km (10k feet) or lower) and the interference signal is transmitted from the airborne radar main beam,
2. the airborne station is at low altitude (3 km (10k feet) or lower) and the interference signal is received by the FS antenna main beam, or
3. any situation with main beam to main beam coupling.

Note that since both the FS antenna and the airborne radar have narrow beams, the probability of these three cases occurring is small. The interference condition is considered short-term if the probabilities of occurrence of all of these three events are below values such as those established by the ITU. The I/N criteria can be relaxed for a short-term interference problem. The probabilities of the three cases occurring are calculated in Annex B; the result shows that when the airborne antenna depression angle is larger than 15° , the probabilities of the first two cases are on the order of 10^{-5} while that of the third case is 10^{-10} . Therefore, they are considered short-term phenomena, and the I/N criteria derived in Annex D are based on guidelines for the short-term interference condition.

III. Mitigation Techniques

Recommendation IPU-R F.1097 provides numerous mitigation techniques for solving interference problems between the FS and RLS systems. However, for the FS system envisioned in the 92-95 GHz band, almost none of the techniques are applicable. This is largely due to the very high gigabit capacity and the required bandwidth. A detailed

explanation is provided in Annex C

IV. FS Point-to-Multipoint Communications

The current design concept for the **FS** system in this band uses pencil-shape beams to provide a point-to-point (P-P) connection; this is the scope of this study. Follow-on systems may include point-to-multipoint (P-MP) connection with wide beams. The wider beam and lower gain of the FS antenna pattern will significantly increase the probability of unacceptable interference occurrence as compared to the P-P case. For the P-MP case, the I/N criteria derived for the short-term condition become inapplicable. Further study needs to be conducted to consider this case if such systems are developed.

V. Conclusion

Point-to-point FS and airborne RLS systems can share the 92-95 GHz band if the FS system is designed with typical large fade margins to combat rain fading. However, interference is possible from airborne RLS systems operating at altitudes below 3 km (10k feet) or with antenna depression angles of less than 15°.

Annex A. Millimeter Wavelength FS and Airborne RLS Systems

A.1 Technical data of FS and airborne RLS systems in the millimeter wavelength range

Interference analysis between the FS and airborne RLS systems requires the technical characteristics of the two systems. However, with few operational FS or airborne RLS systems in the 92-95 GHz band, these system characteristics have been assumed based on technical characteristics of several FS and airborne RLS systems in the millimeter wavelength (30 GHz to 300 GHz) range.

Technical characteristics of several millimeter wavelength FS systems are shown in Table A.1

Table A.1 Sample millimeter wavelength FS system characteristics

System	1		3	4
Operating frequency (GHz)	92.1-93.2, 93.9-95.0	92-100	64-66	71-76
Bit rate (Mbps)			155	1250
Emission bandwidth (MHz)	1000	266-4530		1750
Modulation type			16-QAM	On-off keying
Max. output power (W)*			0.01	0.03
Antenna gain (dBi)			45	51 (2-ft dish) or 56 (4-ft dish)
Transmit EIRP (dBW)	41.8	58.4	25	35.8-40.8
Receiver IF bandwidth (MHz)			40	1600
Receiver noise figure (dB)			9	7
Required C/N (dB)			21	16
Source	Trex Enterprises Corp., NG017988, NG017989	Boeing Corp., NG028309	ITU-R F.758, Table 28	LOEA Communications Corp., www.loeacommunications.com

*: The transmit power was 1 W or 0.1 W in the initial design of system #4, providing a rain fade margin of at least 50 dB and availability of better than 99.999% over I-mile link for most part of the United States except the extreme Southeast region. The system design was later modified to reduce the power to 0.03 W to reduce the receiver dynamic range. The current design has a rain fade margin of 30 dB over I-mile link. and automatic transmit power control (ATPC) technique will be incorporated to achieve the availability objective.

Technical characteristics of-several millimeter wavelength airborne RLS systems are shown in Table A.2.

Service	radiolocation	-	
		radiolocation	radiolocation
Operating frequency (GHz)	02-96	94	94.92
Emission Bandwidth (MHz)	50: 500	290	100
Pulse width (μ s)	5	0.02-0.04	2
Pulse rate (pps)	10,000-30,000	20,000-80,000	N/Avail
Radar gain (dBi)	40	39	25
Max. power (W)	2000	57	1500
Radar scan range ($^{\circ}$)	elevation: +15 to -45, azimuth: +/- 45	N/Avail	N/Avail
Function and status	air-to-ground targeting, experimental	ground target illumination, experimental	cloud detection, operational

Technical characteristics of RLS systems are function dependent and show wide variations even in the same band.

A.2 FS and airborne RLS system parameters for the 9295 GHz band

The FS system characteristics for this study are derived from Table A.1, and are listed in Table A.3. These parameters are largely drawn from system #4, which is being developed to provide fiber-optic speed communications in the 71-76 GHz band.

Operating frequency (GHz)	92-95
Bit rate (Mbps)	1250
Noise bandwidth (MHz)	1600
Max. output power (W)	0.03 (note 1)
Antenna gain (dBi)	51. 56 (note 2)

Antenna sidelobe (dBi)	$32 - 25 \cdot \log(\theta)$, leveling at -10 (note 3)
Receiver noise figure (dB)	7
Required C/N (dB)	16
Atmospheric gaseous loss (dB/km)	0.5
<p>note 2: 51 dBi for 1-mile hop, 56 dBi for longer hop.</p> <p>note 3: from ITU-R F.699-5. Sidelobe performance of system #4 is reported better.</p>	

The airborne RLS system characteristics for this study are derived from Table A.2, and are listed in Table A.4. These data are largely drawn from system #1

Table A.4 Airborne RLS system parameters for interference evaluation

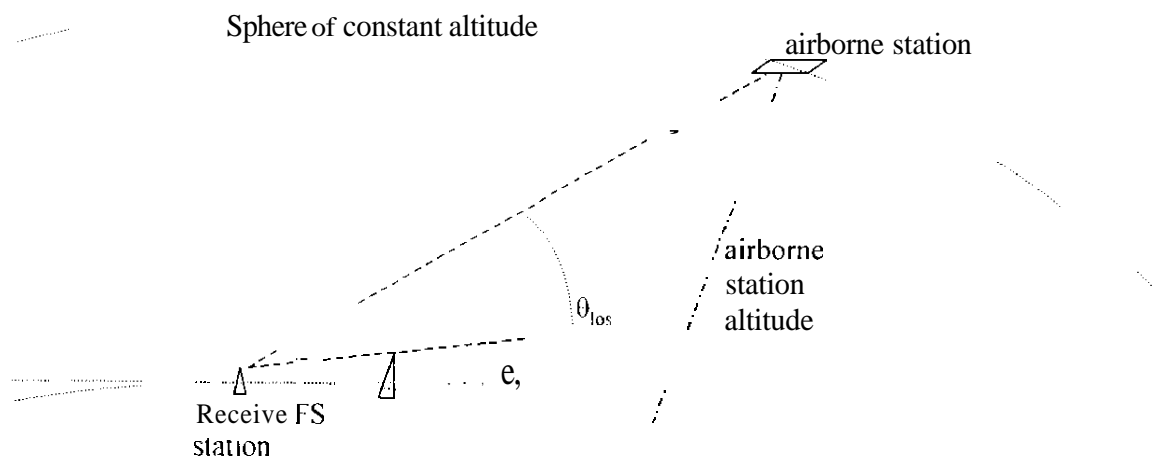
Operating frequency (GHz) 92-95
Emission bandwidth (MHz)

Radar far sidelobe (dBi)	
Max. Power (W)	2000
Pulse width (μ s)	5
Pulse rate (pps)	20,000
Radar scan (")	elevation: +15 to -45. azimuth: +/- 45

RLS system characteristics can vary widely even in the same band.

A.3 Carrier and interference power calculation

The interference geometry of this calculation is shown in Figure A.1. The geometry is in spherical coordinates with the Earth center as its origin. For convenience in formulating the analysis, the FS station-to-airborne station line-of-sight elevation angle (not the line-of-sight distance) is the variable.



θ_e : FS receive antenna elevation angle

θ_{los} : FS station-to-airborne station line-of-sight elevation angle

Figure A1 Geometry for interference calculation

First, the link budget of the FS system is calculated. Because these system parameters are derived from system #4 of Table A.1, the result highlights some special features in that system. Two link budgets are shown in Table A.5, one for a one-mile hop and the other for a five-mile hop.

Table A.5 Link budget of FS system

1	Nominal hop distance (mile)	1	5
2	Frequency (GHz)	92	92
3	IF bandwidth (MHz)	1600	1600
4	Transmit antenna gain (dBi)	51	56
5	Transmit peak power (W)	0.03	0.03
6	Transmit eirp (dBW)	35.8	40.8
7	Receive antenna gain (dBi)	51	56
8	Slant path distance (km)	1.6	8
9	Free space loss (dB)	135.8	149.8
10	Atmospherical gaseous loss (dB/km)	0.5	0.5
11	Antenna front end power flux density (dBW/m ²)	-40.1	-52.3
12	Carrier power (dBW)	-49.8	-57.0
13	Receiver noise figure (dB)	7	7
14	Receiver output noise (dBW)	-104.9	-104.9
15	C/N (dB)	55.1	47.9
16	C/N requirement (dB)	16	16
17	Rain fade margin (dB)	39.1	31.9

The system has rain fade margin provision of over 30 dB. However, because of the rain fade condition in this band, ATPC is still needed to achieve desirable availability objectives in most hops.

The interference analysis calculates the I/N value at a FS receiver output. Sample analysis are shown in Tables A.6-7 with the FS antenna elevation angles of 10° and 0°, respectively. The 10° elevation angle is likely the upper limit for a FS link hop length of 1 km or more, and the 0° elevation angle represents a nominal value. Here, four cases are presented:

- case 1: interference from the airborne radar sidelobe to the FS antenna sidelobe,
- case 2: interference from the airborne radar sidelobe to the FS antenna main beam:
- case 3: interference from the airborne radar main beam to the FS antenna sidelobe,
- case 4: interference from the airborne radar main beam to the FS antenna main beam

In this calculation, the I/N threshold in row 21 is discussed in Annex D; the airborne station altitude is assumed to be 9 km.

Table A.6 Sample Interference analysis for FS antenna 10° elevation angle

		case 1 (SL-SL)	case 2 (SL-MB)	case 3 (MB-SL)	case 4 (MB-MB)
1	Frequency (GHz)	92	92	92	92
2	FS IF bandwidth (MHz)	1600	1600	1600	1600
3	Effective Earth radius (km)	8500	8500	8500	8500
4	Airborne station altitude (km / feet)	9 / 30k	9 / 30k	9 / 30k	9 / 30k
5	FS station-to-airborne station line-of-sight elevation angle (°)	20	10	20	10
6	FS station-to-airborne station line-of-sight distance (km)	26.2	51.0	26.2	51.0
7	Airborne radar antenna gain (dBi)	40	40	40	40
8	Airborne radar peak power (W)	2000	2000	2000	2000
9	Airborne radar eirp (dBW)	73.0	73.0	73.0	73.0
10	Airborne radar directional gain toward FS station (dBi)	0	0	40	40
11	FS receive antenna gain (dBi)	51	51	51	51
12	FS receive antenna elevation angle (°)	10	10	10	10
13	FS receive antenna directional gain toward airborne station, $32-25\log(\theta)$ (dBi)	7.0	51.0	7.0	51.0
14	Free space loss (dB)	160.1	165.9	160.1	365.9
15	Atmospherical gaseous loss (dB/km)	0.5	0.5	0.5	0.5

16	FS receive antenna front end power flux density (dBW/m ²)	-79.5	-97.6	-39.5	-57.6
17	FS received interference power (dBW)	-133.2	-107.3	-93.2	-67.3
18	FS receiver noise figure (dB)	7	7	7	7
19	FS receiver output noise (dBW)	-104.9	-104.9	-104.9	-104.9
20	FS I/N (dB)	-28.3	-2.4	11.8	37.6
21	FS I/N requirement (dB)*	-10	25	25	> 29
22	Interference margin (dB)	18.3	27.4	13.2	> -8.6
23	Approx. probability of occurrence**	<1	<10 ⁻⁵	<10 ⁻⁵	<10 ⁻¹⁰
* Data derived in Annex D					
** Data derived in Annex R					

Table A.7 Sample Interference analysis for FS antenna 0° elevation angle

		case 1 (SL-SL)	case 2 (SL-MB)	case3 (MB-SL)	Case 4 (MB-MB)
1	Frequency (GHz)	92	92	92	92
2	FS IF bandwidth (MHz)	1600	1600	1600	1600
3	Effective Earth radius (km)	8500	8500	8500	8500
4	Airborne station altitude (km / feet)	9 / 30k	9 / 30k	9 / 30k	9 / 30k
5	FS station-to-airborne station line-of-sight elevation angle (°)	20	0	20	0
6	FS station-to-airborne station line-of-sight distance (km)	26.2	391.3	26.2	391.3
7	Airborne radar antenna gain (dBi)	40	40	40	40
8	Airborne radar peak power (W)	2000	2000	2000	2000
9	Airborne radar eirp (dBW)	73.0	73.0	73.0	73.0
10	Airborne radar directional gain toward FS station (dBi)	0	0	40	40
11	FS receive antenna gain (dBi)	51	51	51	51
12	FS receive antenna elevation angle (°)	0	0	0	0
13	FS receive antenna directional gain toward airborne station. 32-25log(0) (dBi)	-0.5	51.0	-0.5	51.0
14	Free space loss (dB)	160.1	183.6	160.1	183.6
15	Atmospherical gaseous loss (dB/km)	0.5	0.5	0.5	0.5
16	FS receive antenna front end power flux density (dBW/m ²)	-79.5	285.1	-39.5	-245.4

17	FS received interference power (dBW)	-140.7	-295.2	-100.7	-255.2
18	FS receiver noise figure (dB)	7	7	7	7
19	FS receiver output noise (dBW)	-104.9	-104.9	-104.9	-104.9
20	FS I/N (dB)	-35.8	-190.2	4.2	-150.2
21	FS I/N requirement (dB)*	-10	25	25	> 29
22	Interference margin (dB)	25.8	215.2	20.8	> 179.2
23	Approx. probability of occurrence**	<1	<10 ⁻⁵	<10 ⁻⁵	<10 ⁻¹⁰
* Data derived in Annex D					
** Data derived in Annex B					

Using the methodology of Tables A.6-7, the variation of I/N vs. line-of-sight elevation, angle (which is related to the line-of-sight distance) for various FS antenna elevation angles are shown in Figures A.2 and A.3, where the interference power is from the airborne radar sidelobe (0 dBi gain) and main beam (40 dBi gain) in Figures A.2 and A.3, respectively. **Also**, the variation of I/N vs. line-of-sight elevation angle for various airborne station altitudes are shown in Figures A.4 and A.5, where the interference power is from the airborne radar sidelobe (0 dBi gain) and main beam (40 dBi gain) in Figures A.4 and A.5, respectively. The spikes in the curves result from the FS antenna main beam and near sidelobe. As discussed in Annex D, the interference criteria are different, depending on the probability of occurrence.

From Figures A.2-5, for:

- 1 case #1 (airborne radar sidelobe transmission and FS antenna sidelobe reception), from Figure **A.4**, the interference level is not a problem unless the airborne station altitude is about 3 km (10k feet) or lower,
- 2 case #2 (radar sidelobe transmission and FS antenna main beam reception), from Figure **A.4**, the interference level is not a problem unless the airborne station altitude is about 1.5 km (5k feet) or lower.
- 3 case #3 (radar main beam transmission and FS antenna sidelobe reception), from Figure A.5, the interference level is not a problem unless the airborne station altitude is about 3 km (10k feet) or lower,
- 4 case #4 (main beam coupling). from Figures A.3 and A.5, the level of interference appears to be a problem from a strict power standpoint. However, the probability of occurrence for this situation is so low that the interference criterion is not defined and that no measurable impact on FS performance is expected.

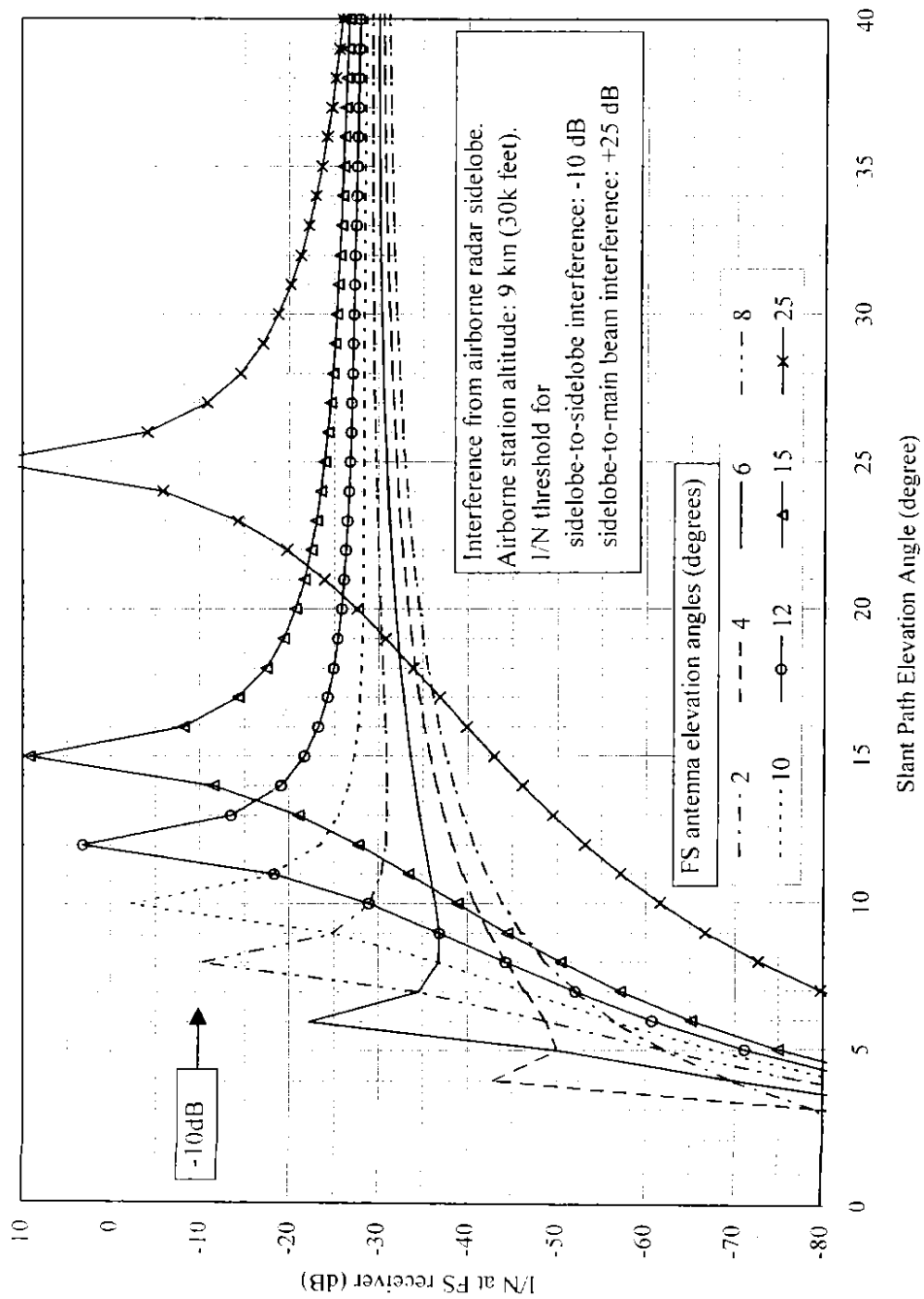


Figure A.2 I/N vs. slant path elevation angle for various FS antenna elevation angles when interference power is from airborne antenna sidelobe

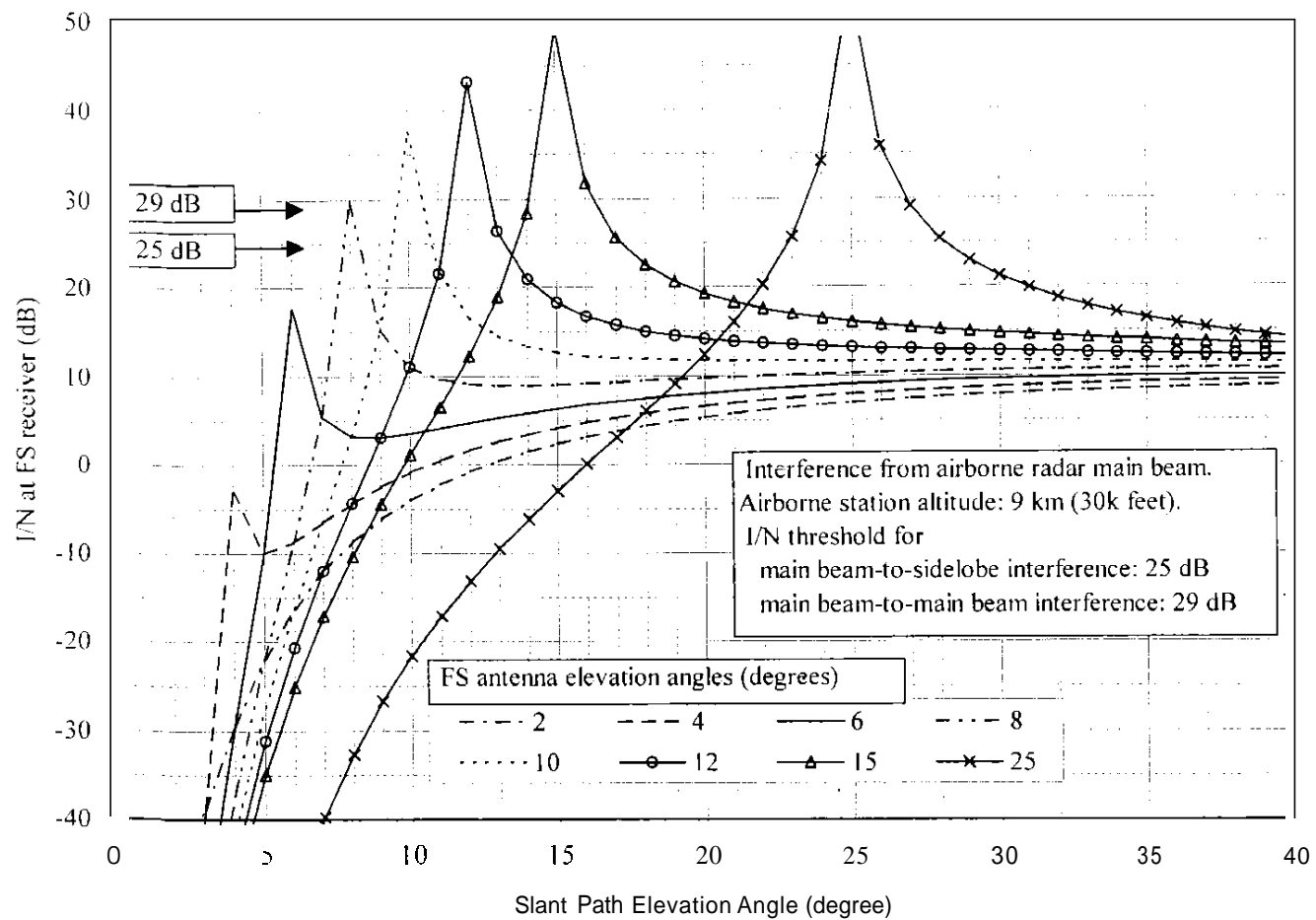


Figure A.3 I/N vs. slant path elevation angle for various FS antenna elevation angles when interference power is from airborne antenna main beam

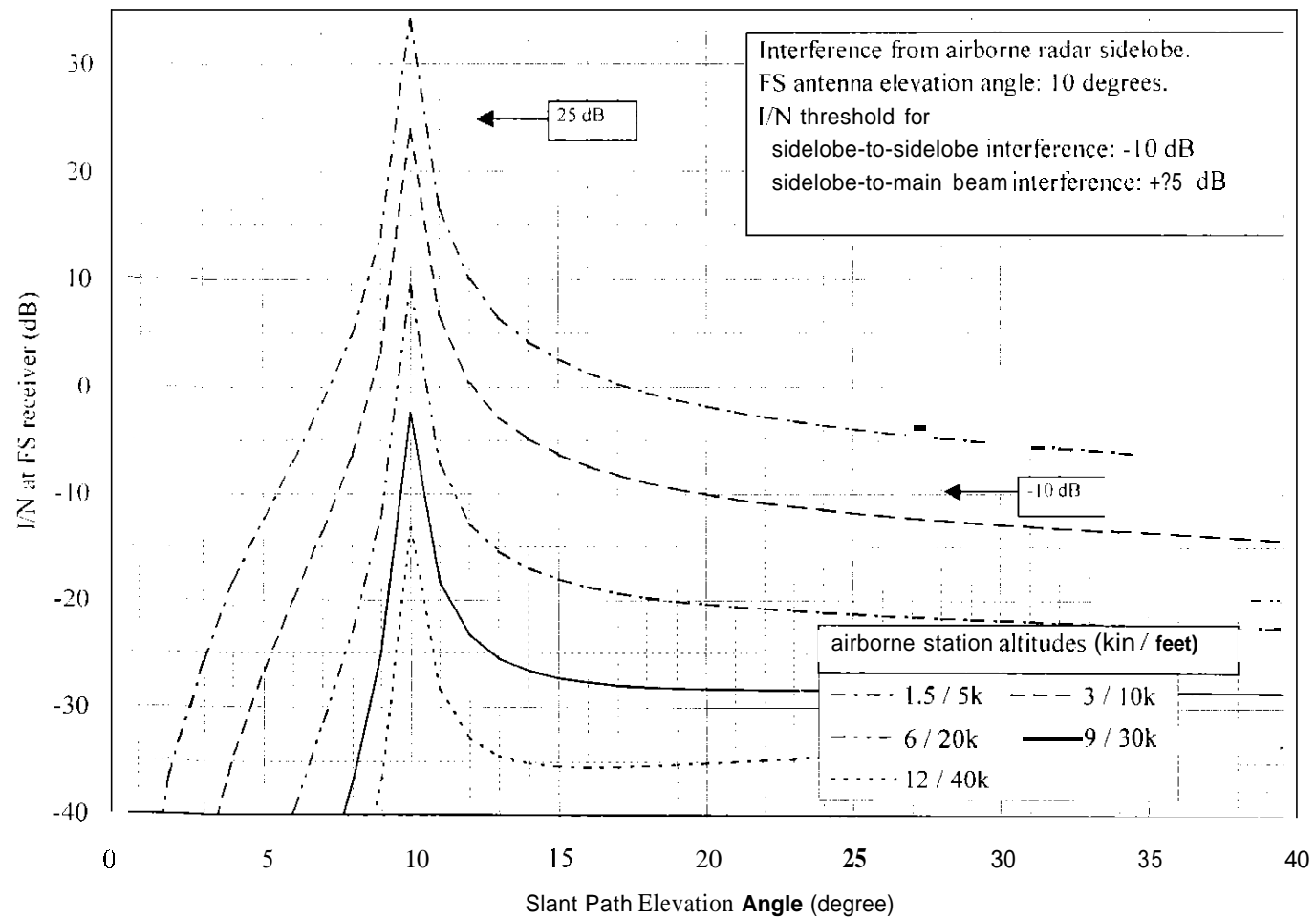


Figure A.4 I/N vs. slant path elevation angle for various airborne station altitude when interference power is from airborne antenna sidelobe

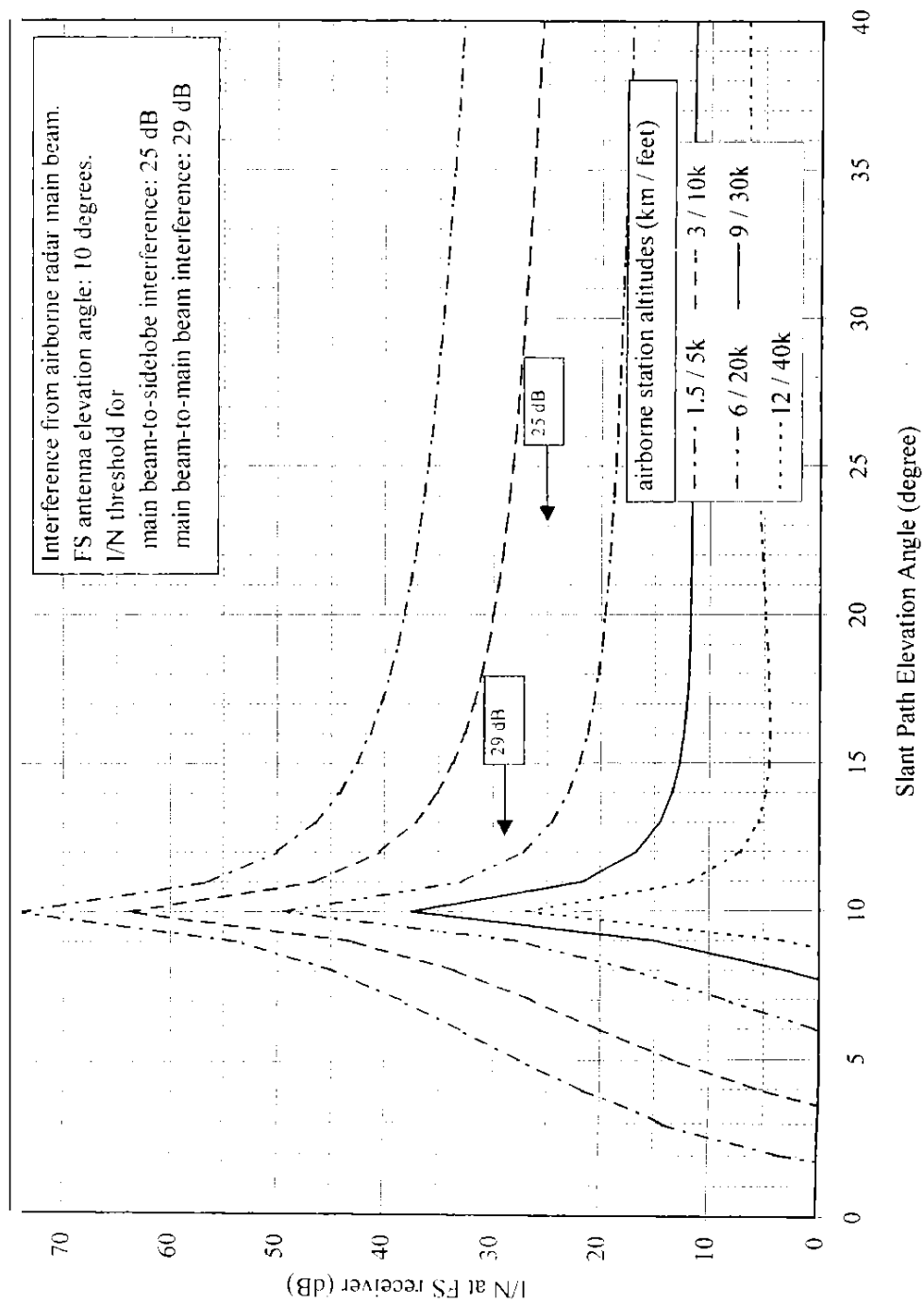


Figure A.5 I/N vs. slant path elevation angle for various airborne station altitude when interference power is from airborne antenna main beam

Annex B. Probability of Main Beam Coupling

B.1 Introduction

The analysis in Annex A indicates that the interference levels can be significant in the main beam coupling situation. Because of the mobility of the airborne station, occurrence of such event becomes a statistics problem. This annex attempts to derive the probability of such event occurring.

A complete analysis should first derive the probability of an airborne station appearing over a FS station horizon. It then calculates the probability of the airborne station appearing in the FS antenna main beam (i.e., interference power received by the FS antenna main beam). It then calculates the probability of the airborne radar aiming at the FS station (i.e., interference power transmitted from the airborne radar main beam). The probability of main beam coupling is the multiplication of the three factors. However, the first factor requires knowledge of the airborne **RLS** system operation, and is beyond the scope of this study. Therefore, this study addresses this with an assumption that an airborne **RLS** system is always in view of the FS receiver, and is equally likely to be at any location within this field of view.

Here it is assumed that the airborne **RLS** system uses a ground mapping radar with a fixed downward aiming direction. The calculation is formulated in spherical coordinates. The probability is approximately the ratio of two geometric areas: an area covered by the main beam and the whole visible area.

B.2 Probability of airborne station appearing in FS antenna main beam

The geometry for calculating the probability of an airborne station appearing in a FS antenna main beam is shown in Figure B.1.

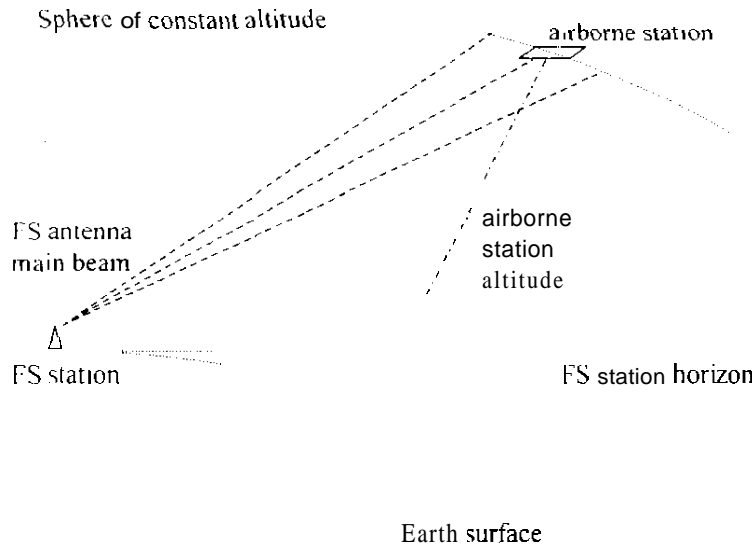


Figure B.1 Geometry of airborne station in FS antenna main beam

First: the spherical area where an airborne station (at a certain altitude) is visible from a FS antenna is calculated. Then, the area the FS antenna main beam intersects the spherical area of visibility is calculated. Their ratio is the probability. The methodology is shown in Table B.1.

Table B.1 Sample calculation of probability of airborne station in FS antenna main beam

1	Effective Earth radius (km)	8500.00
2	Airborne station altitude (km / feet)	9.00 / 30k
3	Geocentric angle for airplane visible by FS station (°)	5.27
4	Spherical area for airplane visible by FS station (km ²)	481172.61
5	FS antenna elevation angle (°)	10.00
6	Main beam center line-of-sight distance (km)	50.98
7	FS antenna HPBW (°)	0.60
8	Main beam upper edge line-of-sight distance (km)	49.55
9	Elliptical intersection near side radius (km)	1.45
10	Main beam lower edge line-of-sight distance (km)	52.48
11	Elliptical intersection far side radius (km)	1.53
12	Elliptical intersection middle side radius (km)	0.27
13	Ellipse area (km ²)	1.25
14	Probability	3×10^{-6}

This probability as a function of airborne station altitude for various FS antenna elevation angles is shown in Figure B.2.

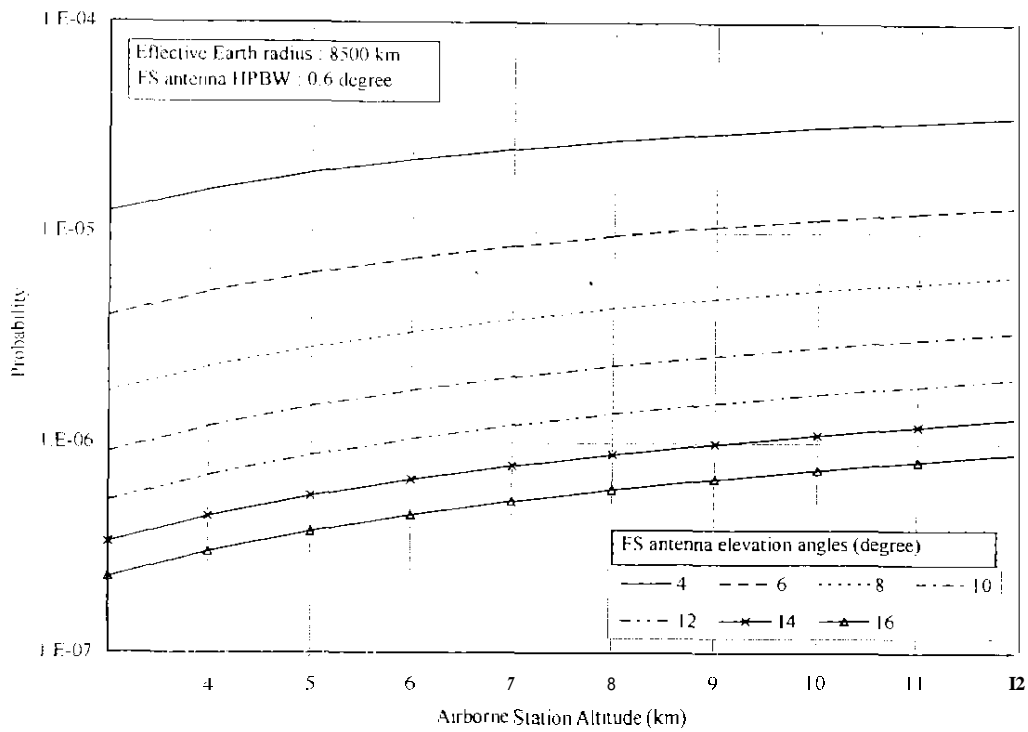


Figure B.2 Probability of airborne station in FS antenna main beam

It is known from Section A.3 that interference level is not a concern if the FS antenna elevation angle is below 6° . Therefore, for airborne station altitudes and FS antenna elevation angles that may cause interference, the probability of an airborne station appearing in a FS antenna main beam is below 10^{-5} .

B.3 Probability of airborne radar aiming at FS station

The geometry for calculating the probability of an airborne radar aiming at a FS station is shown in Figure B.3.

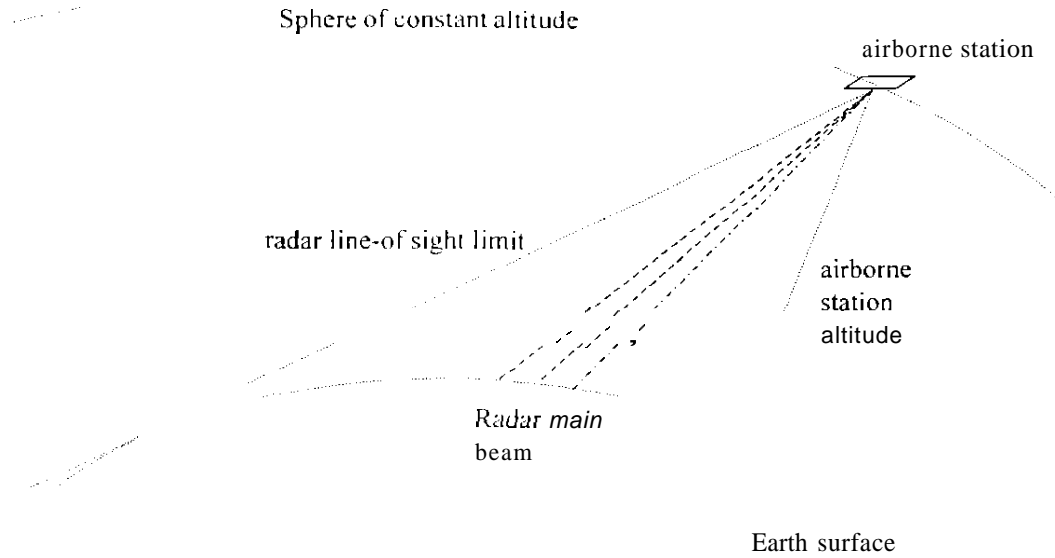


Figure B.3 Geometry of airborne radar aiming at FS station

First, the Earth surface area visible by an airborne station (of certain altitude) is calculated. Then, the surface area intersected by the radar main beam is calculated. Their ratio is the approximate probability. The methodology is shown in Table B.2.

Table B.2 Sample calculation of probability of airborne station in FS antenna main beam

1	Effective Earth radius (km)	8500.00
2	Airborne station altitude (km)	9.00
3	Surface area viewable from airborne station (km ²)	480155.28
4	Airborne radar main beam down tilt elevation angle (°)	40.00
5	Main beam center line-of-sight distance (km)	14.01
6	Radar HPBW (°)	1.60
7	Main beam upper edge line-of-sight distance (km)	14.25
8	Elliptical intersection long side radius (km)	0.31
9	Main beam lower edge line-of-sight distance (km)	13.78
10	Elliptical intersection short side radius (km)	0.30
11	Elliptical intersection middle side radius (km)	0.20
12	Ellipse area (km ²)	0.19
13	Probability	4×10^{-7}

This probability as a function of airborne station altitude for various radar down tilt aiming angles is shown in Figure B.3.

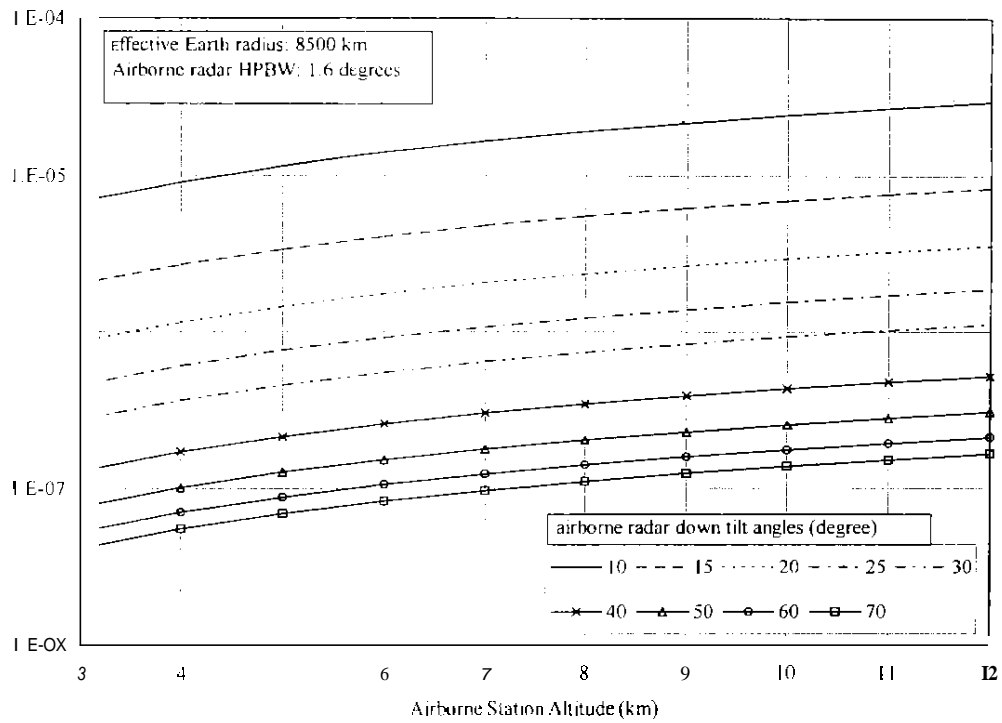


Figure B.4 Probability of airborne radar aiming at FS station

It is seen that the probability is below 10^{-5} when the airborne radar down tilt aiming angle is larger than 15° .

B.4 Probability of main beam coupling

The probability of main beam coupling is the multiplication of the two factors in Sections B.3 and B.4. Therefore, its value is below 10^{-10} .

Annex C. Conventional Mitigation Techniques

Recommendation ITU-R F.1097 provides many mitigation techniques to alleviate interference problems between the FS and RDS systems.¹ However, due to the special features of the FS system envisioned in the 92-95 GHz band, most of the techniques are not applicable for reasons explained as follows:

1. Band segmentation: The envisioned FS system will provide fiber-optic speed service of Gbps capacity, and the bandwidth requirement is in GHz range. Therefore, the system will need the complete 92-95 GHz band. Band segmentation would disallow such design, and should not be implemented.
2. FS signal processing: The FS bit rate is on the order of Gbps, while the airborne radar pulse width is on the order of microseconds. Each radar pulse can corrupt approximately 10^3 contiguous FS bits. None of the currently available forward error correction (FEC) coding scheme, bit interleaving technique (BIT), nor any modulation technique can correct such a pattern of error.
3. ATPC: ATPC allows a FS system to operate with less fade margin, and instead relies on ATPC to counter short-term deep rain fade conditions. Use of ATPC in this band may be an operational requirement. Unfortunately, use of ATPC will provide less immunity against short-term interference from RLS systems since it prevents the use of a large fade margin to suppress the airborne radar interference pulses.
4. Airborne radar RF filter: RF filter installation will reduce the spectral sidelobe power, and is very effective in reducing adjacent channel interference. Without band segmentation, the FS and KLS signals are always co-channel and RF filtering provides no benefit.

¹ Rec. ITU-R F.1097-1, *Interference Mitigation Options to Enhance Compatibility between Radar Systems and Digital Radio-relay Systems*, Volume 2000, Series F, Part 1(A)

Annex D. Derivation of Interference Protection Criteria

D.1 Introduction

In undertaking this study, recommendations of the ITU-R and other sources were reviewed to identify appropriate interference protection criteria for airborne RLS to FS interference. While no sources were identified that specifically addressed this issue in the region of 95 GHz, relevant data were identified within ITU-R texts from which to derive appropriate values. The criteria described herein is based primarily on methodology described in Appendix 7 of the ITU-R Radio Regulations and Recommendation ITU-R F.1495.² The two key factors to consider were:

- 1) Should the interference levels be based on peak power *or* average power? and
- 2) What are the acceptable levels for long-term and short-term interference?

D.2 Peak power vs. average power

As described in Annex C, a single interfering pulse on the order of a microsecond, with sufficient power, can result in the loss of upwards of 1000 contiguous data bits, because of the very high FS data rate being planned. No currently available FS signal processing technique can recover this scale of data loss, as might be the case if only a few data bits were lost per interfering pulse. Recommendation ITU-R F.1190 investigates the impact of radar interference to FS systems operating below 7 GHz and recommends that the interference protection criteria be based on peak interference power.³ That recommendation would clearly apply in this case as well. Measurements completed by NTIA further confirm that for interference where the pulse length is very long compared to the FS symbol rate, peak power levels should be used.⁴ Consequently, for the case under study all interference power levels should be peak pulse power.

D.3 Long-term interference

From a number of ITU-R recommendations, long-term interference in FS systems is defined as interference that occurs for 20% or more of the time. Under the assumption used in this study that an airborne RLS is always in view of the FS receiver, a long-term interference

² Recommendation ITU-R F.1495, *Interference criteria to protect the fixed service from time varying aggregate interference from other services sharing the 17.7-19.3 GHz band on a co-primary basis*, Volume 2000, Series F, **Pan 1(A)**

³ Recommendation ITU-R F.1190, *Protection criteria for digital radio-relay systems to ensure compatibility with radnr systems in the radiodetermination service*, Volume 2000, Series F, **Pan 1(A)**

⁴ Sanders, Frank H., *Measurements of pulsed co-channel interference in a 4-GHz digital earth station*, NTIA Report 02-393, May 2002

protection criteria is appropriate to use for the case of sidelobe-to-sidelobe interference.

Recommendation ITU-R F.1094 defines the maximum allowable performance degradation to FS due to interference from other sources.⁵ Specifically, this recommendation states that interference from other services sharing a band on a primary basis should degrade the FS performance by no more than 10%. For FS systems operating below about 13 GHz where multipath fading predominates, it can be shown, using analytic techniques described in Recommendation ITU-R F.1108, that 10% performance degradation will occur when a continuous interfering signal is present at $I/N = -10$ dB.⁶ For FS systems operating above 13 GHz where rain fading predominates, a direct correlation between I/N levels and performance degradation was not found. Nevertheless, the long-term interference protection criteria of $I/N = -10$ dB, corresponding to a loss in fade margin of about 0.5 dB, is used in several studies of FS systems operating above 13 GHz such as Recommendation ITU-R F.1495 and others. The following long-term interference protection criterion is adopted for the case under study:

$$I_{pk}/N \text{ should not exceed } -10 \text{ dB for more than 20\% of time} \quad (D-1)$$

D.4 Short-term interference

Annex B shows that interactions involving antenna main beam coupling between RLS and FS systems will occur typically with quite low probability; consequently, use of short-term interference protection criteria is appropriate. Fixed systems always employ moderate to high link margins to counter the effect of fading. Numerous studies within the ITU-R have shown that FS systems subjected to short-term, intermittent interference can withstand a higher level of interference as compared to the long-term value. Recommendation ITU-R F.1190 investigates protection criteria for digital FS systems from radar interference. It recommends an $I/N = +10$ dB protection criteria from maritime and land mobile radar interference. No specific time percentages are associated with this recommendation. However, it is clear that the recommendation does not address the much lower probability of occurrence would result from antenna main beam interactions involving airborne RLS systems nor does it address systems above 7 GHz.

For very low probability events, such as would occur from airborne RLS and/or FS

⁵ Recommendation ITU-R F.1094-1, *Maximum allowable error performance and availability degradations to digital radio-relay systems arising from interference from emissions and radiations from other sources*, Volume 2000, Series F, Part 1(A)

⁶ Recommendation ITU-R F.1108-2, *determination of the criteria to protect fixed service receivers from the emissions of space stations operating in non-geostationary orbits in shared frequency bands*, Annex 3, Volume 2000, Series F, Part 2

main beam interactions. the methodology described in Appendix 7 of the ITU-R Radio Regulations and Recommendation ITU-R F.1495 would be applicable. From these sources, it is assumed that for very short-term interference, the FS link is at its nominal unfaded level. Consequently, interference would have to overcome the full fade margin to result in any performance degradation. The following generic short-term criterion can be derived:

$$I_{pk}/N \text{ should not exceed } [NFM - Y] \text{ for more than } X\% \text{ of time} \quad (D-2)$$

where NFM in dB is the net fade margin = total fade margin – ATPC range

The NFM for a FS system is normally defined using a $BER = 10^{-3}$ reference level. However, FS performance is defined within ITU-R texts using a slightly different reference level, which the Y term accounts for. The applicable percent of time, X, varies depending on several factors including the nature of the FS circuit (i.e., long haul, short haul, local loop, etc.), number of hops, and data rate. For this study, the percent of time is based on the assumption that the FS system is for short haul service composed of 5 hops and data rate of greater than 55 Mb/s.⁷ Using the methodology described in the recommendation, two short-term criteria result as follows:

$$I_{pk}/N \text{ should not exceed } [NFM - 5 \text{ dB}] \text{ for more than } 0.026\% \text{ of the time} \quad (D-3)$$

$$I_{pk}/N \text{ should not exceed } [NFM - 1 \text{ dB}] \text{ for more than } 0.0003\% \text{ of the time} \quad (D-4)$$

These short-term criteria are applied for this study using NFM of 30 dB. The combined long-term and short-term limits are shown in Figure D-1. Any combination of I_{pk}/N and probability of occurrence should fall below the curve. The procedures defined in Recommendation ITU-R F.1495 specifies three data points and does not specify a continuous curve nor define a methodology for interpolation between the specified data points. Figure D-1 suggests one possible interpolation method.

⁷ The current recommendation does not address data rates higher than 160 Mb/s; however, the values used herein would represent a worst case for such data rates.

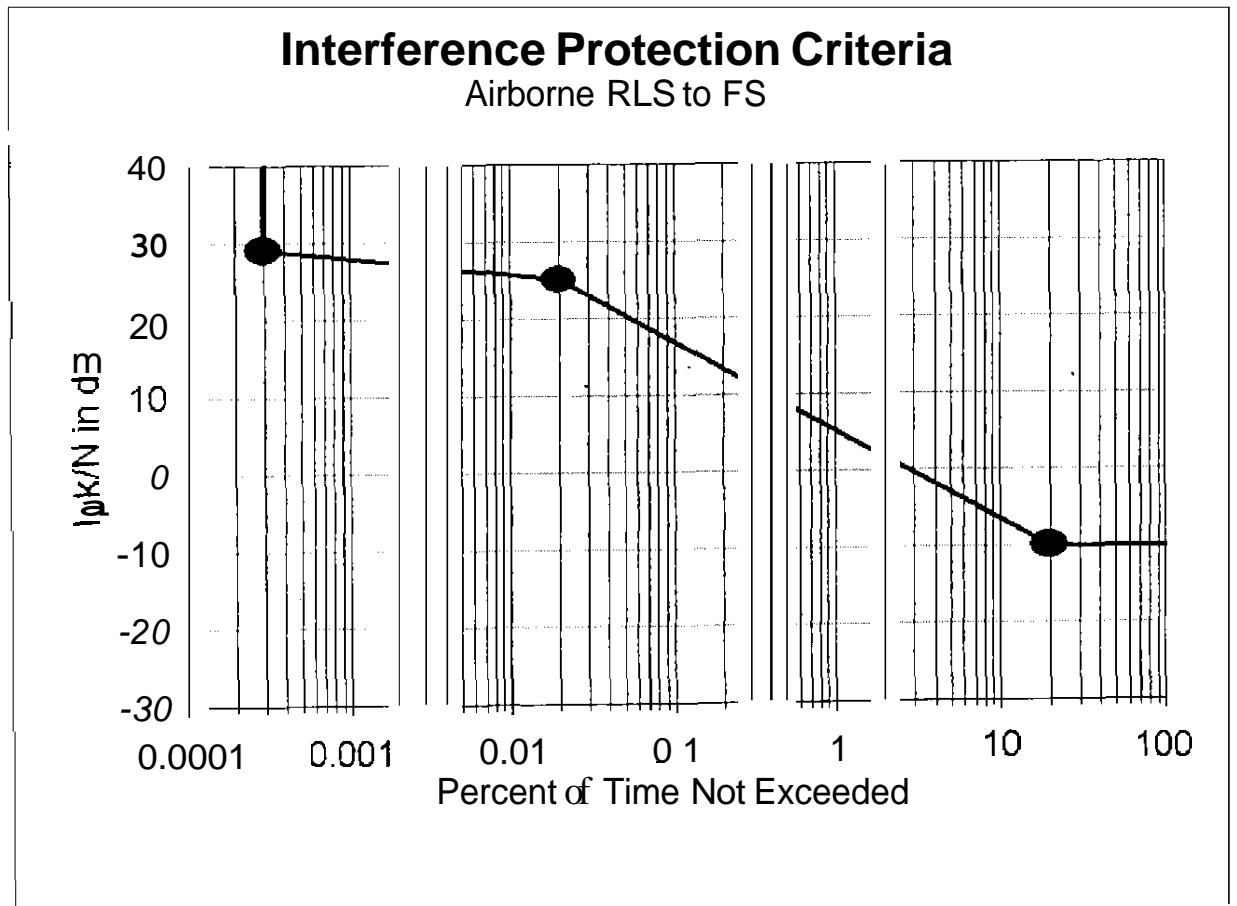


Figure D-1 Interference protection criteria